BARIUM, ZINC AND CERIUM DOPED TRANSITION METAL OXIDE NANOPARTICLES FOR PHOTOCATALYTIC AND BIOMEDICAL APPLICATIONS

SYNOPSIS

Submitted in partial fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY
in
CHEMISTRY

Submitted by

Shweta Kaushal
Enrollment No.: H220264

Under the supervision of

Dr. Kuldeep Kumar
Associate Professor

DEPARTMENT OF CHEMISTRY
SCHOOL OF BASIC & APPLIED SCIENCES
CAREER POINT UNIVERSITY HAMIRPUR
TIKKER (KHARWARIAN), BHORANJ
HAMIRPUR (HP)-176041, INDIA

2022-2023

1. Introduction

1.1. Nanotechnology

As the name suggests, nanotechnology deals with nanomaterials in the range of 1 to 100 nanometers (nm) and their applications in various fields such as material science, chemistry, physics, and biology. The Nobel Prize-winning physicist Richard Feynman introduced the concept of nanotechnology at an American Physical Society meeting at the California Institute of Technology on December 29, 1959. He hypothesized the concept behind nanotechnology that *"There is a Plenty of Room at the Bottom".* Later, after a decade, Professor Norio Taniguchi of Tokyo Science University coined the term "*Nanotechnology*" in 1974. Today nanotechnology presents pioneering opportunities helpful in curing several major problems in the domains of energy, medicine, environment, food production, electronics, sports, fabrics, textiles, pharmaceuticals, and information around the world (Naseem & Durrani, 2021).

1.2. Nanoparticles

A nanoparticle is defined as a particle of matter between 1 to 100 nm in diameter. Nanoparticles (NPs) differ from micro particles (ranging from 1-1000 μm) and coarse particles (ranging from 2500 to 10^4 nm) because of their small size and high surface-to-volume ratio. Being at the changeover position between bulk material and atomic or molecular structure they disclose extra-ordinary properties or phenomena that are not observed at micro or coarse scale. The unique characteristics of NPs help them to show exceptional physical and chemical properties. The class of NPs is very wide which includes substances that have at least one dimension less than 100 nm and can be 0D, 1D, 2D, and 3D (Khan, Saeed & Khan, 2019). The types of NPs are many such as carbon-based, ceramic, metallic, semiconductor, polymeric, composite, biological, quantum dots, organic, and lipid NPs. And metal oxides come under the category of semiconductor NPs, which are well-known as prominent photocatalysts having properties of both, metal and non-metal with wide band gaps. Thus, by tuning the band gap of metal oxide NPs, their properties can be improved efficiently for the applications like anti-microbial and photocatalysis (Bhatia, 2016). There are plenty of examples of metal oxide nanoparticles that have been used till date for the applications like photocatalysis, energy storage, environmental, biomedical, gas-sensing, waste-water treatment, catalytic, electronic and magnetic applications, but some of the prominent ones are as follows –

1.2.1. Copper Oxide

Copper is one of the most abundant transition-metal in the Earth's crust with the electronic configuration (Cu: [Ar] $3d^{10}4s^{1}$). Among the transition metal oxides, copper oxides have gained much interest of researchers because of its promising applications in various fields. Copper oxide exists in two different forms which differ from each other in terms of valence state of copper: cupric oxide (CuO) and cuprous oxide (Cu_2O) (Sayed, A.M & Shaban, 2015). Copper oxide is a p-type semiconductor with a narrow band gap 1.7 eV. Copper oxide NPs are extensively investigated for the applications like drug delivery, anticancer, antioxidant, antibiotics, gas sensors, conducting materials, photocatalysis and in catalytic processes (Waris et al., 2020).

1.2.2. Cobalt Oxide

Cobalt is one of the only three ferromagnetic transition metals along with iron and nickel with electronic configuration (Co: [Ar] $3d^{7}4s^{2}$). Cobalt oxide exists as Cobalt (II) oxide and Cobalt (III) oxide which have normal spinel structure with the formula Co_3O_4. Recently cobalt oxide nanostructures have also fascinated the researchers because of their high mechanical strength and chemical stability (Sivalingam, Murugan & Vijaya, 2022). Cobalt oxide is a p-type semiconductor with optical band gap 1.48 and 2.19 eV and are used in various applications like chemical sensors, electrochromic devices, photocatalysis, heterogeneous catalysis and biomedicine (Manjula et al., 2021).

1.2.3. Titanium Dioxide

Titanium is a transition metal with atomic number 22 and Titanium dioxide (TiO_2) NPs are by far the most attractive choice among researchers as they are discovered earliest and extensively investigated. Due to their high chemical stability, environmental inertness and relatively low cost, TiO_2 is one of the most widely used transition metal for the synthesis of photocatalytic material (Silva et al., 2015). Many metal and non-metal doped TiO_2 NPs are prepared till date to enhance the properties of these NPs for efficient photocatalytic and antibacterial activities (Mazierski et al., 2018).

1.2.4. Doped/co-doped metal oxides

The addition of impurities in the material for the enhancement of either electrical, optical or structural properties is generally known as doping. So, the dopant act as an impurity which trigger several features of material because of the defects introduced in the material after doping (Medhi, Marquez & Lee, 2020). Introduction of another component whether metal, non-metal or any kind of impurity leads to significant changes in the energy gap of the material (Chavali & Nikolova, 2019). An accurate choice of dopant will result in the material which gives certain specific applications (Chen et al., 2005). Therefore, the

dopant helps in influencing the electronic structure of metal oxide semiconductor thereby enhancing the absorption of a material from UV light to rest of the solar spectrum which remain unused otherwise, resulting them in better photocatalyst (Marschall & Wang, 2013).

1.2.5. Synthetic Routes

There are two approaches namely top-down and bottom-up approach to synthesize metal oxide NPs. These approaches involve chemical, physical and green methods for the preparation of metal oxide NPs. Metal precursors, stabilizing agents and reducing agents are the main components of chemical approach. Some examples of chemical methods are sol-gel, co-precipitation, chemical reduction and reverse micelle etc. Physical approach mainly works on the top-down approach in which precursor is reduced in small size via various physical methods. The commonly used physical methods are spray pyrolysis, ultra-sonication, laser ablation and vaporization etc (Gour & Jain, 2019). But green approach is gaining interest from the past few years because of the ease of availability, handling and synthesis of the NPs. The biogenic reduction of metal precursor works by bottom up approach which is similar to chemical method where reducing agent is replaced by a biological extract. The biological probes used for the green synthesis can be microbes, plants, algae and biomimetic. Thus, the green synthesis is an emerging approach for the synthesis of metal oxide NPs for the sustainable, eco-friendly and free of chemical contaminants which may lead to several environmental concerns (Hussain et al., 2016). There are several medicinal plants/herbs which have been used till date like citrus plants, *neem, bael, aloe-vera*, *ashavgandha* and *tulsi* as shown in Figure 1.

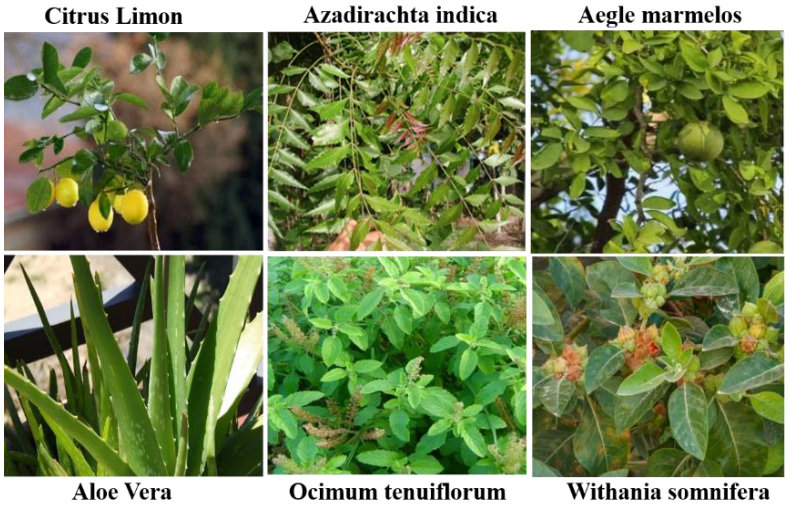

Figure 1. Examples of medicinal plants

From the ancient times, the plants have been the vital sources of many natural products having great potential for the production of materials which have biological activities. So Citrus plants are one of the plants which have gained greater interest of researchers because of the bioactive components present in them. Lemon is one of the medicinal plants which belongs to the Rutaceae family. The term "*Lemon*" comes from French language "*Limon*". Citrus fruits are generically termed as "*Lime*" which is connected to "*Nimbu*" in Sanskrit (Qudah et al., 2018). The extract of different parts of lemon plant like leaves, stem, root, juice, peel and flower have anticancer and antibacterial potentials because of the alkaloids present in it (Hindi, Khazal & Chabuck, 2013). The fruits and leaves of the citrus plants have large number of flavonoid glycosides which have anti-carcinogenic and anti tumour activities (Kawaii et al., 2000). Therefore, lemon plant own several characteristics which leads to the antimicrobial, antiviral, antifungal, anti-inflammatory and anti-cancer activities and these characteristics can be exploited to formulate a material which is far more beneficial in comparison to conventional one (Qudah et al., 2018). Another therapeutically important plant used since many years for the synthesis of metal oxide NPs is Neem. Neem (*Azadirachta indica)* belongs to the Meliaceae family which has several therapeutic implications in curing many diseases. The constituents of Neem include polyphenolic flavonoids which shows outstanding antifungal and antibacterial activities. This medicinal plant is known to exhibit several pharmacological and biological applications like antitumour, antibacterial, anti-inflammatory and antifungal (Gopalakrishnan & Muniraj, 2021). *"Aegle marmelos"* which is commonly known as Bael and is renowned for its therapeutic effectiveness since time immemorial. It is known for its antioxidant, antibacterial, antifungal, antiviral and antidiabetic activities (Ezhilarasi et al., 2018).

Therefore, it can be summarized that there are different types of NPs which serve the purpose to tackle various environmental problems, but metal oxide NPs emerging out as one of the efficient nanomaterials for the issues related to water contamination, soil contamination, anti-microbial, antioxidant activities and photocatalysis. And green synthesis of NPs is more beneficial technique whether in decreasing cost, energy requirements, pollution or in improving human health and environmental safety. Therefore, the combination of the metal oxide NPs with the medicinal plant/herbs is a reliable remediating tool for the burning problems in the present scenario that can be referred to or cured.

2. Literature Review

Metal oxide NPs are among the most widely used semiconductor nanomaterials and play magnificent role in the various fields of science and technology. They have attracted the attention of researchers in the field of material sciences due to unique physical and chemical features related to shape and size contributing to the localized surface plasmon resonance. Some of recent studies documented in literature on metal oxides NPs have been summarized in the following paragraphs to highlight the potential of these nanostructures.

2.1. Copper Oxide Nanoparticles

Rodney et al. (2022) analyzed critically the effect of dopant concentration on the crystallite size, morphology, potential values, and application for oxygen evolution reactions of dysprosium (Dy) doped cupric oxide NPs synthesized by using co-precipitation method. The dopant concentration increases the crystallite size by replacing the Cu^{2+} with Dy^{3+} in the crystal lattice. The so-obtained cupric oxide electrode also exhibited low onset potential value of 1.40 V as compared to the commercially available electrodes.

Uma et al. (2020) compared the green synthesis route (using Aloe Vera gel) and co-precipitation route for the preparation of cupric oxide. The green method beneficially decreases the crystallite size and showed strong interactions between NPs and Aloe Vera gel. The green synthesized cupric oxide NPs showed (92%) degradation of methylene blue (MB) and other synthesized route showed (84%) degradation for the same. Furthermore, the prepared NPs also exhibited good antibacterial activity. Therefore, the synthesized green NPs found to be promising for further biological investigations.

Aadil et al. (2021) reported the wet chemical route for the facile synthesis of binary metal substituted copper oxide which can act as solar light driven photocatalyst and antibacterial alternative. The inclusion of manganese and silver showed outstanding photocatalytic activity (83.9% degradation of MB) with the synthesized copper oxide NPs. The binary substituted copper oxide exhibited superior potential to kill both the Gram negative and Gram-positive bacteria. Therefore, as synthesized copper oxide NPs presented other choices of the material for bacterial pathogens and photocatalysis.

Yuan et al. (2020) worked on the synthesis of efficient photoelectric material of zinc (Zn), cerium (Ce) and both doped cuprous oxide by using hydrothermal method. The morphology of doped cuprous oxide got evolved from irregularly cubic structure to regular octahedron and spherical aggregate as compared to pure cuprous oxide. The prepared NPs

work actively in visible region due to increase in band gap and the growth mechanism which evidences that the aggregation, diffusion and reaction temperature were the main factors affecting crystal growth was effectively explained by the authors.

Ce doped copper oxide NPs were synthesized by Velliyan & Rajendran, (2021) via combustion technique to study the effect of doping on the structural, morphological and optical properties. With the increase in the concentration of dopant, the particle size decreases and the samples have changed their morphology from spherical to dumbbell shape. Furthermore, the band gap values of samples were increased from 1.2 to 1.3 eV with the concentration of cerium in the copper oxide crystal lattice.

Rafique et al. (2020) reported the biological synthesis of copper oxide NPs using leaves extract of *citrus aurantifolia* and highlighted the cost-effectiveness, non-toxicity and eco-friendly behavior of opted method. The efficiency of synthesized copper oxide NPs was analyzed for the application of photocatalysis and anti-bacterial activity which showed 91 % Rhodamine B (RhB) removal and good antibacterial efficiency. Thus, biosynthesized copper oxide NPs can be potential material for dye removal and antibacterial agent for contaminated water.

Ramaswamy, Narendhran & Sivaraj, (2015) studied the potentiating effect of brown algae mediated synthesis of copper oxide NPs for antimicrobial and anticancer activities. The synthesized NPs killed the Pseudomonas aeruginosa (15±0.5 mm) pathogen most effectively. And the cytotoxicity was evaluated against MCF-7 cell line on varying the concentration, 93 % of effective cell inhibition was observed.

Sayed & Shaban, (2015) studied the structural, optical and photocatalytic properties of synthesized cobalt (Co) and iron (Fe) co-doped copper oxide spin coated films. The crystallite size decreases with Fe doping but it gradually increases with the co-doping of cobalt. The band gap values also showed blue shift first and then red shift after co-doping. The photocatalytic degradation of MB enhanced as compared to the single doping. Therefore, the so-obtained material using sol-gel spin coating technique has shown potential in optoelectronic devices.

Adeleye et al. (2018) reported the influence of Fe doping in copper oxide for colloidal stability and toxicity of copper oxide in synthetic and natural water. The critical coagulation concentration of NaCl showed the decrease in colloidal stability with Fe doping. Moreover, the dissolution study confirmed the leaching of copper with the increase in Fe concentration. Therefore, the Fe doping did not affect the marine species but total suspended copper dominated the dissolved copper complexes in seawater.

Jadhav et al. (2011) studied the synthesis, characterization and antibacterial activity of copper oxide NPs. The NPs were synthesized via electrochemical reduction method under inert atmosphere of N_2 for 2 hour and solvent polarity, concentration of stabilizers, current density and distance between electrodes were the parameters to control the size of NPs. The antibacterial results proved to be promising for the wide applications.

2.2. Cobalt Oxide Nanoparticles

Reena et al. (2020) reported the chromium (Cr) incorporated cobalt oxide NPs by using lucid co-precipitation method for the investigation of structural, optical and electrical nature of cobalt oxide NPs for photocatalytic degradation of MB. The crystallite size decreases with the increase in the concentration of Cr and the dielectric properties measurement showed that there was an increase in electrical properties with the incorporation of Cr without disturbing spinel structure. The 99% degradation of the adsorbed dye molecules was observed in 60min. Thus, the synthesized cobalt oxide NPs showed extensive possibilities to the industrial applications.

The promotional effects in catalytic activity of cobalt oxide nanoparticles for the 4-nitrophenol reduction studied by Mogudi et al. (2017) after incorporation of alkali and alkaline earth metal. There were no significant changes in the structure after incorporation of dopants and the temperature programmed reduction analysis confirmed the change in electronic structure after doping. Among alkali and alkaline earth metals, the calcium doped cobalt oxide showed the best catalytic activity which followed the Langmuir-Hinshelwood mechanism. Thus, the so-obtained NPs exhibited the capability to replace the expensive noble metals in reactions of synthetic chemistry.

Gopinath, Mayakannan & Vetrivel, (2021) reported the microwave irradiation method for the synthesis of silver (Ag) doped cobalt oxide NPs. The effect on structural, optical and morphological properties were examined with the Ag doping. The crystallite size increases with the increase in doping concentration and there was decrease in band gap value with the increase in the concentration of dopant. The highest weight percentage doped concentration showed the best antibacterial results because good electrostatic interaction between cobalt oxide NPs and the microorganism is the reason behind this. Therefore, the prepared NPs can emerge out as the suitable option for biomedical applications.

An easy synthesis of amorphous film of Ce doped cobalt oxide as an efficient electrocatalyst for the oxygen evolution reaction was reported by Xu et al. (2019). The electrostatic spray method was used for the deposition of amorphous film of the Ce on the

cobalt oxide. The incorporation of Ce in the lattice of cobalt oxide reduces the crystallinity. The Ce introduced oxygen vacancy in the lattice was the main factor to increase the electrochemical surface area and intrinsic activity of the catalyst for the oxygen evolution reaction. Thus, the prepared catalyst was competitive to the commercially available RuO_2.

Sivachidambaram et al. (2017) proposed an economically novel and green synthesis based nanocatalyst of cobalt oxide for the catalytic applications. The *Azadirachta indica* mediated synthesis using hot plate combustion method resulted in the hollow sphere like NPs with antiferromagnetic nature. The benefits of various important constituent containing NPs gave outstanding results in photocatalytic, antibacterial and catalytic applications. Therefore, the novel synthesis of cobalt oxide NPs emerge out as multifunctional material for environmental remediation.

Bibi et al. (2017) studied the *Punica granatum* peel extract mediated synthesis of cobalt oxide NPs at low temperature for the photocatalytic activity of Remazol Brilliant Orange 3R (RBO 3R) dye, giving 78.45 % degradation of dye on irradiation for 50 min. Therefore, by keeping in mind the eco-benign and cost-effective nature of the *Punica granatum*, this plant could be used for the photocatalytic applications.

Lee et al. (2015) reported the modification of titanium dioxide with cobalt oxide NPs for photocatalysis using liquid phase plasma method. Being less photoactive than bare titanium dioxide in UV light, a visible light active photocatalyst was prepared by precipitating cobalt oxide NPs on the titanium dioxide powder. Therefore, cobalt oxide proved to be promising in enhancing photocatalytic activity of titanium dioxide.

Alwan, Alshamsi & Jasim, (2018) worked on the composite of reduced graphene oxide (rGO) with cobalt oxide NPs for adsorption of Rhodamine B from contaminated water. The nanocomposite displayed very good adsorption results under different pH, ionic strengths and temperature. So, the obtained nanocomposite can be used for wide applications.

Rasheed et al. (2019) presented the biogenic synthesis of cobalt oxide NPs using *Taraxacum officinale* plant as a potential source in stabilizing the NPs. The yielded NPs employed for the dye degradation of azo dyes - direct yellow-142 (93.37 %) and methyl orange (MO) (96.24 %) suggests that the green and eco-friendly synthesis of cobalt oxide NPs could be a potent candidate to degrade azo dyes and other contaminants in better manner.

The photocatalytic properties of mesoporous and macro porous Ag doped cobalt oxide nano sheets studied by Aadil et al. (2020) under solar light irradiation. The

outstanding catalytic activity was observed for MB dye showing 88.4 % degradation at the rate constant (k) of 2.1 $\times 10^{-2}$ min^{-1} due to narrower band gap and high surface area. Therefore, the Ag doped cobalt oxide in exposure of solar light emerges out as beneficial for removal of industrial effluents.

2.3. Titanium Dioxide Nanoparticles

Lassoued et al. (2018) synthesized the cobalt doped titanium dioxide (TiO_2) nanostructures by using co-precipitation method for photocatalytic activity. The dopant ions were well dispersed in the TiO_2 crystal and the size decreases continuously with the increase in the dopant concentration. There was remarkable decrease in the band gap values of un-doped and doped TiO_2 nanostructures. Among the doped TiO_2 NPs, the 6% doped TiO_2 showed the best photocatalytic degradation of MO.

Nickel (Ni) with Gallium (Ga) and Zn was codoped in TiO_2 by Dakhel, (2020) using thermal co-precipitation method. The doping with non-magnetic Ga and Zn ions helped in inducing magnetic properties in the hydrogenated Ni doped TiO_2 sample. The conclusions showed that the structural point defects like oxygen vacancies were the main reasons for creating ferromagnetic parameters and codoped TiO_2 can exhibit potential application in solar cells, gas-sensing and optoelectronics like fields.

Li et al. (2020) have studied enhanced photocatalytic activity under visible light irradiation for the Gadolinium (Gd), Fe and nitrogen (N_2) codoped TiO_2 nanomaterials. The codoped samples were synthesized by using sol-gel method with slight modification. The notable enhancement in the photocatalytic activity of codoped TiO_2 was observed due to more defects introduced, oxygen vacancies, larger specific surface area and narrower band gap. The significant improvement was observed due to the presence of active hydroxyl radicals which enhanced the degradation of MB as compared to the un-doped TiO_2. The efficiency of photocatalyst was about 95% even after five cycles of the photocatalytic experiment.

Peng, Guo & Lin, (2019) reported the synthesis of Samarium (Sm) doped TiO_2 NPs for the photocatalytic reduction of CO_2. The Sm doped TiO_2 nanocomposites was efficiently prepared via sol-gel method. The results confirmed that the Sm dopant has inhibitory effect on the growth of anatase particles. The optical properties showed that the activity of the prepared catalyst was enhanced in the UV and visible regions. The carbon mono-oxide and methane yields were increased by 5.02 and 2.67 times of pure TiO_2. The enhancement in the doped sample was ascribed due to the lower recombination rate of

electron hole pair and high visible light response. Thus, the prepared TiO_2 sample emerge out as a better option for photocatalytic reduction of CO_2.

Ali et al. (2018) reported the synthesis of Ag doped TiO_2 photocatalyst via sol-gel method for the degradation of MB. The yielded photocatalyst employed for the degradation of dyes showed super stability and durability giving 89 % efficiency even after the five successive runs. Furthermore, with the Ag concentration in so-obtained TiO_2, the bactericidal enhancement was observed. Therefore, the efficiency of Ag doped TiO_2 was examined by photo-degradation of MB.

Yang et al. (2014) examined the copper (Cu) doped TiO_2 for the photocatalytic performance of MO dye under UV irradiation. The XPS showed the enhanced oxygen trapping capability of TiO_2 lattice and induction of more oxygen vacancy after doping with Cu. The decrease in recombination rate of electron-hole pair in doped TiO_2 NPs lead to the improved photocatalytic degradation of MO.

The comparative study of chemical method and aqueous extract of *Malva parviflora* for plant mediated synthesis of visible light active Sulphur (S) doped TiO_2 was reported by Helmy et al. (2021). The excellent reducing and capping properties of plant helped to grow anatase phase of TiO_2 NPs with S-doping. The green TiO_2 more effectively degraded the MO and showed higher anti-bacterial and anti-oxidant activities. Therefore, the greenly prepared doped TiO_2 NPs can be endorsed specifically for the applications of waste water treatment and drug delivery.

Hariharan et al. (2020) studied the Aloe vera gel mediated approach for the hydrothermal synthesis of Ag doped TiO_2 NPs. The photocatalytic degradation of picric acid showed wonderful results within 50 min endorsing the impact of morphology acquired due to capping/reducing agent. Furthermore, the prepared NPs showed high visible light absorption resulted in higher production of reactive oxygen species leading to enhancement in anticancer activity.

Photocatalytic degradation of alkaline earth metal (Sr) doped TiO_2 NPs have been described by Sood et al. (2015). The hydrothermal cum ultrasound method resulted in high surface area and mesoporosity leading to sunlight assisted photocatalytic degradation of brilliant green dye within 60 min. Therefore, the utilization of solar light for degradation of harmful organic contaminants by alkaline earth doped TiO_2 can be promoted for wide applications.

Nabi et al. (2020) used lemon peel extract for the photocatalytic degradation of RhB using TiO_2 NPs. The aglycone constituent of lemon peel acted as capping and

reducing agent which lead to spherical morphology having 80 to 140 nm size. The resulted NPs have less band gap value of 3.08 eV, degrading the 70 % dye efficiently. Therefore, the as-synthesized TiO_2 NPs can be promoted for the applications like biomedicine, water cleaning, and energy production.

Therefore, it can be concluded that the diversity of transition metal oxides for the applications of photocatalysis is very large. And the documented studies in the literature, related to transition metal oxides and doped/co-doped transition metal oxides are highly known for the pollutant degradation, environmental remediation, and clean energy. One of the major strategies to optimize the nanomaterial for better photocatalytic and anti-microbial activity is to introduce a new contributor to lattice structure along with biogenic material leading to exceptional improvements for future applications.

3. Research Gap Identification

There are different physical and chemical methods for synthesizing metal oxide NPs, but the need to prepare less toxic and more application-efficient material is essential. Although many researchers have synthesized doped/co-doped metal oxide NPs, but the studies of incorporating lanthanides and alkaline earth metals as dopants and co-dopants in transition metal oxide NPs by using green methods are almost absent from the literature and many properties are yet to be found. Hence, the present study will investigate the effect of doping/co-doping of lanthanide and alkaline earth metal with the transition metal which attracted the focus of the present research in this area. Furthermore, the use of synthesized NPs for photocatalytic and anti-bacterial activity will also be studied.

4. Objectives

The objectives of the present study are as follows:

- To synthesize the biogenic doped/co-doped transition metal oxide NPs using the co-precipitation method.
- To characterize the synthesized NPs by using different characterization techniques like Scanning electron microscope (SEM) and Transmission electron microscope (TEM), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), UV-visible spectroscopy, etc.
- To study the photocatalytic activity of synthesized NPs by using different dyes.

- To study the antibacterial activity of synthesized NPs by using different bacterial strains.
- To study the antioxidant potential of synthesized NPs using the DPPH assay method.

5. Proposed Methodology

In present study, we endorsed the green synthesis for metal oxide NPs which involves the use of plant extract of *Citrus Limon* for the synthesis of doped NPs using co-precipitation method.

5.1. Materials

Cupric nitrate trihydrate (99.5%, AR), Zinc nitrate hexahydrate (98%, AR), Cobalt nitrate hexahydrate (98%), Sodium hydroxide (98%), and Cerium nitrate hexahydrate will be procured from Merck. Double distilled water will be used in all experiments during the study. Plant leaves of *Citrus Limon* will be collected from local areas of district Hamirpur, Himachal Pradesh for the preparation of extract.

5.2. Methods

5.2.1. Synthesis of Plant Extract

The standard method of extraction as reported by Siddique et al. (2020) will be used in the present study to prepare plant extract. In its procedure, first of all the fresh leaves of *Citrus Limon* plant will be collected from local areas of district Hamirpur, Himachal Pradesh. The collected leaves will be washed properly with tap water and then with distilled water to remove the dust, microorganism, any particles or other impurities that may be on the leaves. Fixed amount of washed leaves will be weighed and then they will be chopped well to prepare paste with the help of mixer grinder. The prepared paste will be boiled at 70-80 ºC for about 30-35 minutes in an appropriate volume of distilled water. The assembly will consist of the attachment of the condenser with the round bottom flask standing on the rota-mantle with constant stirring. The boiled extract will be cooled and filtered through Whatman filter paper. The filtered extract solution will be used for the synthesis of NPs.

5.2.2. Green synthesis of doped/co-doped Nanoparticles

The co-doped NPs will be synthesized by using co-precipitation method (Pilecka et al., 2011). For the synthesis of co-doped NPs, Cupric nitrate trihydrate, Zinc nitrate hexahydrate, Cobalt nitrate hexahydrate, Cerium nitrate hexahydrate will be used as precursors. Plant extract will be used as reducing/stabilizing agent in the green synthesis

process. For co-doping synthesis, the calculated amount of metal salt precursor will be dissolved in 100 ml of distilled water in which desired molar concentrations of dopant metal salts will be dissolved in 100 ml of distilled water and further it will be added dropwise for the synthesis of co-doped aqueous solution with constant stirring on magnetic stirring on magnetic stirrer. Then fixed volume of plant extract will then be added in dropwise manner to above solution. For the last step, NaOH will be added to the prepared solution as precipitating agent. The aqueous solution will be stirred on magnetic stirrer for 2 hours at 70-80 ºC temperature. The obtained NPs will be washed several times with distilled water and ethanol. At last, they will be dried in vacuum oven at 1.5 KPa at 70 ºC temperature for 12 hours. After drying in vacuum oven, co-doped metal oxide NPs will be calcined at 350 ºC for 3 hours.

5.3. Characterization of synthesized NPs

The synthesized NPs will be characterized using various characterization techniques to find out the different physical and chemical properties. The crystalline structure, crystallite size, crystal phase and lattice parameters will be determined with the help of the X-Ray Diffraction (XRD). The morphological analysis and particle size will be determined with the help of Scanning electron microscope (SEM) and Transmission Electron Microscope (TEM). Several other characterization techniques like Fourier transform infrared spectroscopy (FTIR) and UV-Vis spectroscopy will also be used to determine the absorption regions of prepared metal oxide NPs.

5.4. Applications of metal oxide NPs

5.4.1. Photocatalytic Activity

The photocatalytic activities of the synthesized NPs will be evaluated by using them for the degradation of commercial dyes. The degradation study will be performed to check the intensity of absorbance peaks after illumination under particular light sources. The procedure will be followed as given by the Sharma et al. (2020) and % degradation will be calculated using the formula-

$$Degradation\ \% = \frac{C_0 - C_t}{C_0} \times 100$$

5.4.2. Antibacterial Activity

The antibacterial activity will be performed for both gram negative and gram-positive bacteria by using well diffusion method. The Staphylococcus aureus (MTCC 737), Bacillus subtilis (MTCC 441) and Escherichia coli (MTCC 739) will be used for the particular study. Bacterial strains will be collected from the Institute of Microbial

Technology (IMTECH), microbial type culture collection center, Chandigarh. The procedure will be followed as given by the Sharma et al. (2021).

5.4.3 Antioxidant Activity

The antioxidant activity assessment will be done by using DPPH (1,1-diphenyl-2-picrylhydrazyl) scavenging assay as described by Faraz et al. (2022). The samples will be examined for the different concentrations in µg/ml and ascorbic acid will be taken as standard. The assessment study will be performed against the DPPH free radical and the percent radical scavenging will be calculated using the formula-

$$Radical\ Scavenging\ Activity\ (\%RSA) = \frac{OD_{control} - OD_{sample}}{OD_{control}} \times 100$$

where OD stands for optical density.

6. Thesis Outline

CHAPTER 1 (Introduction):

This chapter will contain the brief introduction related to the nanotechnology, nanoparticles (NPs), synthesis methods, medicinal plants extract and metal oxide NPs.

CHAPTER 2 (Literature Review):

This chapter will deal with the literature survey of synthesis, characterization and eco-friendly applications of metal oxide NPs.

CHAPTER 3 (Materials and Methods):

This chapter will contain the experimental detail, materials used and discussion about the nanoparticle synthesis methods/methodology, characterizations techniques and applications procedure for the different metal oxide nanoparticles.

CHAPTER 4 (Results and Discussion):

This chapter will discuss the results of performed research work which includes the synthesized nanoparticles characterization results, their analysis and applications of metal oxide nanoparticles.

CHAPTER 5 (Summary and Conclusion):

This chapter will summarize and correlate all the above-mentioned chapters in comprehensive manner.

CHAPTER 6 (References):

This chapter will contain the references of all the concerned work related to the thesis work and literature review.

7. References

Naseem, T. & Durrani, T., (2021) The role of some important metal oxide nanoparticles for wastewater and antibacterial applications: A review. *Environmental Chemistry and Ecotoxicology*. 3, 59-75. https://doi.org/10.1016/j.enceco.2020.12.001

Khan, I., Saeed, K. & Khan, I., (2019) Nanoparticles: Properties, applications and toxicities. *Arabian Journal of Chemistry*. 12 (7), 908-931. https://doi.org/10.1016/j.arabjc.2017.05.011

Bhatia, S. & Bhatia, S., (2016) Nanoparticles types, classification, characterization, fabrication methods and drug delivery applications. *Natural Polymer Drug Delivery Systems: Nanoparticles, Plants, and Algae*, pp. 33-93. https://doi.org/10.1007/978-3-319-41129-3_2

El Sayed, A. M. & Shaban, M., (2015) Structural, optical and photocatalytic properties of Fe and (Co, Fe) co-doped copper oxide spin coated films. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 149, 638-646. http://dx.doi.org/10.1016/j.saa.2015.05.010

Waris, A., Din, M., Ali, A., Ali, M., Afridi, S., Baset, A. & Khan, A. U., (2021) A comprehensive review of green synthesis of copper oxide nanoparticles and their diverse biomedical applications. *Inorganic Chemistry Communications*. 123, 108369. https://doi.org/10.1016/j.inoche.2020.108369

Manjula, N., Chen, T. W., Chen, S. M. & Lou, B. S., (2021) Facile synthesis of hexagonal-shaped zinc doped cobalt oxide: Application for electroanalytical determination of antibacterial drug ofloxacin in urine samples. *Journal of Electroanalytical Chemistry*. 885, 115101. https://doi.org/10.1016/j.jelechem.2021.115101

Sivalingam, S., Murugan, V. and Vijaya, P.P., 2022. Biological investigation of chromium-doped cobalt oxide nanoparticles against HeLa cancer cell lines. *Journal of Materials Science*, *57*(27), pp.12985-12993. https://doi.org/10.1007/s10853-022-07432-0

Da Silva, A. L., Muche, D. N., Dey, S., Hotza, D. & Castro, R. H., (2016) Photocatalytic Nb_2O_5-doped TiO_2 nanoparticles for glazed ceramic tiles. *Ceramics International*. 42(4), 5113-5122. http://dx.doi.org/10.1016/j.ceramint.2015.12.029

Mazierski, P., Mikolajczyk, A., Bajorowicz, B., Malankowska, A., Zaleska-Medynska, A. & Nadolna, J., (2018) The role of lanthanides in TiO_2-based photocatalysis: A review. *Applied Catalysis B: Environmental*. 233, 301-317. https://doi.org/10.1016/j.apcatb.2018.04.019

Medhi, R., Marquez, M. D. & Lee, T. R., (2020) Visible-light-active doped metal oxide nanoparticles: review of their synthesis, properties, and applications. *ACS Applied Nano Materials*. 3 (7), 6156-6185. https://doi.org/10.1021/acsanm.0c01035

Chavali, M. S. & Nikolova, M. P., (2019) Metal oxide nanoparticles and their applications in nanotechnology. *SN Applied Sciences*. 1 (6), 607. https://doi.org/10.1007/s42452-019-0592-3

Chen, X., Lou, Y., Dayal, S., Qiu, X., Krolicki, R., Burda, C., Zhao, C. & Becker, J., (2005) Doped semiconductor nanomaterials. *Journal of Nanoscience and Nanotechnology*. 5 (9), 1408-1420. https://doi.org/10.1166/jnn.2005.310

Marschall, R. & Wang, L., (2014) Non-metal doping of transition metal oxides for visible-light photocatalysis. *Catalysis Today*. 225, 111-135. https://doi.org/10.1016/j.cattod.2013.10.088

Gour, A. & Jain, N. K., (2019) Advances in green synthesis of nanoparticles. *Artificial Cells, Nanomedicine, and Biotechnology*. 47 (1), 844-851. https://doi.org/10.1080/21691401.2019.1577878

Hussain, I., Singh, N. B., Singh, A., Singh, H. & Singh, S. C., (2016) Green synthesis of nanoparticles and its potential application. *Biotechnology Letters*. 38, 545-560. https://doi.org/10.1007/s10529-015-2026-7

Al-Qudah, T. S., Zahra, U., Rehman, R., Majeed, M. I., Sadique, S., Nisar, S., Tahtamouni, R. & Tahtamouni, R. W., (2018) Lemon as a source of functional and medicinal ingredient: A review. *International Journal of Chemical and Biochemical Sciences*. 14, 55-61. ISSN 2226-9614

Gopalakrishnan, V. & Muniraj, S., (2021) Neem flower extract assisted green synthesis of copper nanoparticles–optimisation, characterisation and anti-bacterial study. *Materials Today: Proceedings*. 36, 832-836. https://doi.org/10.1016/j.matpr.2020.07.013

Ezhilarasi, A. A., Vijaya, J. J., Kaviyarasu, K., Kennedy, L. J., Ramalingam, R. J. & Al-Lohedan, H. A., (2018) Green synthesis of NiO nanoparticles using Aegle marmelos leaf extract for the evaluation of in-vitro cytotoxicity, antibacterial and photocatalytic properties. *Journal of Photochemistry and Photobiology B: Biology*. 180, 39-50. https://doi.org/10.1016/j.jphotobiol.2018.01.023

Hindi, N. K. K. & Chabuck, Z. A. G., (2013) Antimicrobial activity of different aqueous lemon extracts. *Journal of Applied Pharmaceutical Science*. 3 (6), 074-078. http://doi.org/10.7324/JAPS.2013.3611

Kawaii, S., Tomono, Y., Katase, E., Ogawa, K., Yano, M., Koizumi, M., Ito, C. & Furukawa, H., (2000) Quantitative study of flavonoids in leaves of Citrus plants. *Journal of Agricultural and Food Chemistry*. 48(9), 3865-3871. https://doi.org/10.1021/jf000100o

Rodney, J. D., Deepapriya, S., Das, S. J., Robinson, M. C., Perumal, S., Katlakunta, S., Sivakumar, P., Jung, H. & Raj, C. J., (2022) Boosting overall electrochemical water splitting via rare earth doped cupric oxide nanoparticles obtained by co-precipitation technique. *Journal of Alloys and Compounds*. *921*, 165948. https://doi.org/10.1016/j.jallcom.2022.165948

Uma, B., Anantharaju, K. S., Renuka, L., Malini, S., More, S. S., Vidya, Y. S. and Meena, S., (2021) Synthesis of CuO samples by co-precipitation and green mediated combustion routes: comparison of their structural, optical properties, photocatalytic, antibacterial, haemolytic and cytotoxic activities. *Ceramics International*. 47 (7), 10355-10369. https://doi.org/10.1016/j.ceramint.2020.10.223

Aadil, M., Rahman, A., Zulfiqar, S., Alsafari, I. A., Shahid, M., Shakir, I., Agboola, P. O., Haider, S. & Warsi, M.F., (2021) Facile synthesis of binary metal substituted copper oxide as a solar light driven photocatalyst and antibacterial substitute. *Advanced Powder Technology*. 32 (3), 940-950. https://doi.org/10.1016/j.apt.2021.01.040

Yuan, B., Liu, X., Cai, X., Fang, X., Liu, J., Wu, M. & Zhu, Q., (2020) Preparation of zinc and cerium or both doped Cu_2O photoelectric material via hydrothermal method. *Solar Energy*. 196, 74-79. https://doi.org/10.1016/j.solener.2019.11.093

Velliyan, S. & Rajendran, V., (2021) Study on the effect of Ce^{3+} doping on structural, morphological and optical properties of CuO nanoparticles synthesized via combustion technique. *Physica B: Condensed Matter*. 613, 413015. https://doi.org/10.1016/j.physb.2021.413015

Rafique, M., Tahir, M. B., Irshad, M., Nabi, G., Gillani, S. S. A., Iqbal, T. & Mubeen, M., (2020) Novel Citrus aurantifolia leaves based biosynthesis of copper oxide nanoparticles for environmental and wastewater purification as an efficient photocatalyst and antibacterial agent. *Optik*. 219, 165138. https://doi.org/10.1016/j.ijleo.2020.165138

Ramaswamy, S. V. P., Narendhran, S. & Sivaraj, R., (2016) Potentiating effect of ecofriendly synthesis of copper oxide nanoparticles using brown alga: antimicrobial and anticancer activities. *Bulletin of Materials Science*. 39, 361-364. https://doi.org/10.1007/s12034-016-1173-3

El Sayed, A. M. & Shaban, M., (2015) Structural, optical and photocatalytic properties of Fe and (Co, Fe) co-doped copper oxide spin coated films. *Spectrochimica Acta Part A:*

Molecular and Biomolecular Spectroscopy. 149, 638-646. http://dx.doi.org/10.1016/j.saa.2015.05.010

Adeleye, A. S., Pokhrel, S., Mädler, L. & Keller, A. A., (2018) Influence of nanoparticle doping on the colloidal stability and toxicity of copper oxide nanoparticles in synthetic and natural waters. *Water Research*. 132, 12-22. https://doi.org/10.1016/j.watres.2017.12.069

Jadhav, S., Gaikwad, S., Nimse, M. & Rajbhoj, A., (2011) Copper oxide nanoparticles: synthesis, characterization and their antibacterial activity. *Journal of Cluster Science* 22, 121-129. https://doi.org/10.1007/s10876-011-0349-7

Reena, R. S., Aslinjensipriya, A., Jose, M. & Das, S. J., (2020) Investigation on structural, optical and electrical nature of pure and Cr-incorporated cobalt oxide nanoparticles prepared via co-precipitation method for photocatalytic activity of methylene blue dye. *Journal of Materials Science: Materials in Electronics*. 31, 22057-22074. https://doi.org/10.1007/s10854-020-04708-6

Mogudi, B. M., Ncube, P., Bingwa, N., Mawila, N., Mathebula, S. & Meijboom, R., (2017) Promotion effects of alkali-and alkaline earth metals on catalytic activity of mesoporous Co_3O_4 for 4-nitrophenol reduction. *Applied Catalysis B: Environmental*. 218, 240-248. https://doi.org/10.1016/j.apcatb.2017.06.045

Gopinath, S., Mayakannan, M. & Vetrivel, S., (2022) Structural, optical, morphological properties of silver doped cobalt oxide nanoparticles by microwave irradiation method. *Ceramics International*. 48 (5), 6103-6115. https://doi.org/10.1016/j.ceramint.2021.11.149

Xu, S., Lv, C., He, T., Huang, Z. & Zhang, C., (2019) Amorphous film of cerium doped cobalt oxide as a highly efficient electrocatalyst for oxygen evolution reaction. *Journal of Materials Chemistry A*. 7 (13), 7526-7532. https://doi.org/10.1039/C9TA00061E

Sivachidambaram, M., Vijaya, J. J., Kaviyarasu, K., Kennedy, L. J., Al-Lohedan, H. A. & Ramalingam, R. J., (2017) A novel synthesis protocol for Co_3O_4 nanocatalysts and their catalytic applications. *RSC Advances*. *7*(62), 38861-38870. http://dx.doi.org/10.1039/c7ra06996k

Bibi, I., Nazar, N., Iqbal, M., Kamal, S., Nawaz, H., Nouren, S., Safa, Y., Jilani, K., Sultan, M., Ata, S. & Rehman, F., (2017) Green and eco-friendly synthesis of cobalt-oxide nanoparticle: Characterization and photo-catalytic activity. *Advanced Powder Technology*. *28*(9), 2035-2043. http://dx.doi.org/10.1016/j.apt.2017.05.008

Lee, H., Park, Y. K., Kim, S. J., Kim, B. H. & Jung, S. C., (2015) Titanium dioxide modification with cobalt oxide nanoparticles for photocatalysis. *Journal of Industrial and Engineering Chemistry*. 32, 259-263. https://doi.org/10.1016/j.jiec.2015.08.025

Alwan, S. H., Alshamsi, H. A. H. & Jasim, L. S., (2018) Rhodamine B removal on A-rGO/cobalt oxide nanoparticles composite by adsorption from contaminated water. *Journal of Molecular Structure*. 1161, 356-365. https://doi.org/10.1016/j.molstruc.2017.11.127

Rasheed, T., Nabeel, F., Bilal, M. & Iqbal, H. M., (2019) Biogenic synthesis and characterization of cobalt oxide nanoparticles for catalytic reduction of direct yellow-142 and methyl orange dyes. *Biocatalysis and Agricultural Biotechnology*. 19, 101154. https://doi.org/10.1016/j.bcab.2019.101154

Aadil, M., Zulfiqar, S., Warsi, M. F., Agboola, P. O., Shakir, I., Shahid, M. & Al-Khalli, N. F., (2021) Mesoporous and macroporous Ag-doped Co_3O_4 nanosheets and their superior photo-catalytic properties under solar light irradiation. *Ceramics International*. 47(7), 9806-9817. https://doi.org/10.1016/j.ceramint.2020.12.121

Lassoued, M. S., Lassoued, A., Ammar, S., Gadri, A., Salah, A. B. & García-Granda, S., (2018) Synthesis and characterization of Co-doped nano-TiO_2 through co-precipitation method for photocatalytic activity. *Journal of Materials Science: Materials in Electronics*. 29, 8914-8922. https://doi.org/10.1007/s10854-018-8910-x

Dakhel, A. A., (2020) Structural, magnetic, and optical properties of degenerated Ni and (Ga/Zn) co-doped TiO_2 nanocomposites. *Applied Physics A*. 126 (12), 948. https://doi.org/10.1007/s00339-020-04131-y

Li, W., Xie, L., Zhou, L., Ochoa-Lozano, J., Li, C. & Chai, X., (2020) A systemic study on Gd, Fe and N co-doped TiO_2 nanomaterials for enhanced photocatalytic activity under visible light irradiation. *Ceramics International*. 46 (15), 24744-24752. https://doi.org/10.1016/j.ceramint.2020.06.265

Peng, H., Guo, R. & Lin, H., (2020) Photocatalytic reduction of CO_2 over Sm-doped TiO_2 nanoparticles. *Journal of Rare Earths*. 38 (12), 1297-1304. https://doi.org/10.1016/j.jre.2019.12.010

Ali, T., Ahmed, A., Alam, U., Uddin, I., Tripathi, P. & Muneer, M., (2018) Enhanced photocatalytic and antibacterial activities of Ag-doped TiO_2 nanoparticles under visible light. *Materials Chemistry and Physics*. 212, 325-335. https://doi.org/10.1016/j.matchemphys.2018.03.052

Yang, X. J., Shu, W. A. N. G., Sun, H. M., Wang, X. B. & Lian, J. S., (2015) Preparation and photocatalytic performance of Cu-doped TiO_2 nanoparticles. *Transactions of Nonferrous Metals Society of China*. 25(2), 504-509. https://doi.org/10.1016/S1003-6326(15)63631-7

Helmy, E. T., Abouellef, E. M., Soliman, U. A. & Pan, J. H., (2021) Novel green synthesis of S-doped TiO_2 nanoparticles using Malva parviflora plant extract and their photocatalytic, antimicrobial and antioxidant activities under sunlight illumination. *Chemosphere*. 271, 129524. https://doi.org/10.1016/j.chemosphere.2020.129524

Hariharan, D., Thangamuniyandi, P., Christy, A. J., Vasantharaja, R., Selvakumar, P., Sagadevan, S., Pugazhendhi, A. & Nehru, L. C., (2020) Enhanced photocatalysis and anticancer activity of green hydrothermal synthesized Ag@ TiO_2 nanoparticles. *Journal of Photochemistry and Photobiology B: Biology*. 202, 111636. https://doi.org/10.1016/j.jphotobiol.2019.111636

Sood, S., Umar, A., Mehta, S. K., Sinha, A. S. K. & Kansal, S. K., (2015) Efficient photocatalytic degradation of brilliant green using Sr-doped TiO_2 nanoparticles. *Ceramics International*. 41(3), 3533-3540. https://doi.org/10.1016/j.ceramint.2014.11.010

Nabi, G., Ain, Q. U., Tahir, M. B., Nadeem Riaz, K., Iqbal, T., Rafique, M., Hussain, S., Raza, W., Aslam, I. & Rizwan, M., (2022) Green synthesis of TiO_2 nanoparticles using lemon peel extract: their optical and photocatalytic properties. *International Journal of Environmental Analytical Chemistry*. *102*(2), 434-442. https://doi.org/10.1080/03067319.2020.1722816

Siddique, M., Khan, N. M., Saeed, M., Ali, S. & Shah, Z., (2021) Green synthesis of cobalt oxide nanoparticles using Citrus medica leaves extract: characterization and photo-catalytic activity. *Zeitschrift für Physikalische Chemie*. 235(6), 663-681. https://doi.org/10.1515/zpch-2019-1583

Sharma, S., Kumar, K., Thakur, N., Chauhan, S. & Chauhan, M. S., (2020) The effect of shape and size of ZnO nanoparticles on their antimicrobial and photocatalytic activities: a green approach. *Bulletin of Materials Science*. 43, 1-10. https://doi.org/10.1007/s12034-019-1986-y

Sharma, S., Kumar, K., Thakur, N., Chauhan, S. & Chauhan, M. S., (2021) Eco-friendly Ocimum tenuiflorum green route synthesis of CuO nanoparticles: Characterizations on photocatalytic and antibacterial activities. *Journal of Environmental Chemical Engineering*. 9 (4), 105395. https://doi.org/10.1016/j.jece.2021.105395

Faraz, A., Faizan, M., Hayat, S. and Alam, P., 2022. Foliar application of copper oxide nanoparticles increases the photosynthetic efficiency and antioxidant activity in Brassica juncea. *Journal of Food Quality*, 2022(1), p.5535100. https://doi.org/10.1155/2022/5535100

CERTIFICATE

(SYNOPSIS APPROVAL CERTIFICATE)

This is to certify that the Synopsis/Revised Synopsis for Ph.D. Thesis titled, **" BARIUM, ZINC AND CERIUM DOPED TRANSITION METAL OXIDE NANOPARTICLES FOR PHOTOCATALYTIC AND BIOMEDICAL APPLICATIONS",** submitted by **Ms. Shweta Kaushal** to the Career Point University, Hamirpur (H.P.), India in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in the Division/Department of **Chemistry**, School of **Basic and Applied Sciences** has been approved by the Research Advisory Committee (RAC) after an Oral Examination of the student on dated **17.06.23**.

Dr. Kuldeep Kumar, Associate Professor
Department of Chemistry, CPU, Hamirpur (H.P.)
(Supervisor)

Research Advisory Committee

Dr. Y.K. Walia, Professor
Department of Chemistry
CPU, Hamirpur (H.P)
(RAC Member)

Dr. Rajender Kumar, Associate Professor
Department of Physics
CPU, Hamirpur (H.P)
(RAC Member)

Dr. Hem Chander, Associate Professor
Department of Botany
CPU, Hamirpur (H.P)
(RAC Member)

Dr. Y.K. Walia, Professor, CPU, Hamirpur (H.P.)
(Head)
Department of Chemistry

Dr. Kuldeep Kumar, Associate Professor, CPU, Hamirpur (H.P.)
(Director Research-cum- Dean Post Graduate Studies)